MECHANICAL PROPERTIES OF ULTRANANOCRYSTALLINE DIAMOND (UNCD) THIN FILMS RELEVANT TO UNCD-MEMS

H. D. Espinosa,[1] George Schatz[2], B. Peng,[1] N. Moldovan,[1]
Orlando Auciello[3] and J. A. Carlisle[3]
[1]Department of Mechanical Engineering, Northwestern University, Evanston, IL
[2]Department of Chemistry, Northwestern University, Evanston, IL
[3]Argonne National Laboratory, Argonne, IL

ABSTRACT

Many Si-based MEMS devices exhibit performance limitations due to the relatively poor physical, mechanical, chemical and tribological properties of Si. Diamond and diamond-like carbon offer several advantages over conventional Si and even SiC as alternate MEMS materials. However, the fabrication of diamond-MEMS components requires a synthesis method capable of producing diamond films with very smooth surface topography, high hardness and fracture strength, low coefficient of friction, and high electrical conductivity, the latter for specific MEMS devices requiring electrostatic actuation. In addition, it is desirable to use microfabrication methods from the Si-MEMS technology. A new diamond film technology developed at Argonne National Laboratory yields phase-pure, low stress ultrananocrystalline diamond (UNCD) layers with 2-5 nm grains and smooth surfaces (20-40 nm rms) that are suitable for fabrication of high-performance MEMS devices. The UNCD films are grown using an Ar-rich CH4 /Ar plasma chemistry that yields high nucleation rate for nanocrystalline diamond growth.

In this presentation, we will review work done to characterize the mechanical properties of UNCD at the MEMS scale. We will discuss studies of the mechanical properties of UNCD film-based MEMS structures fabricated with plain undoped UNCD and nitrogen-doped UNCD. Undoped UNCD films exhibit hardness and Young's modulus similar to single crystal diamond (i.e., 90 GPa and 980 Gpa, respectively), and very low friction coefficient (~ 0.02). Nitrogen-doped films that result in n-type high conductivity UNCD layers exhibit lower hardness than undoped films (reduced to ~80 GPa), but are still suitable for MEMS requiring high conductivity and mechanical strength. The mechanical and electrical properties of UNCD films with and without nitrogen incorporation will be discussed in terms of bulk defects and/or changes in grain and grain boundary structure and size induced by nitrogen incorporation. For example we have determined that the fracture strength of undoped UNCD as yielded from measurements using a membrane deflection method is about 5 GPa, which is lower than the expected intrinsic value for UNCD. Cross-section SEM studies revealed that bulk defects might be responsible for the observed relatively low value of UNCD fracture strength. In addition, nitrogen incorporation to increase UNCD electrical conductivity results in a reduction of fracture strength to about 3 GPa, which might be due to microstructural, dimensional and/or atom bond changes in grain and grain boundaries. The experimental studies will be discussed with respect to computer simulations performed by other members of the NSF NIRT program under which the work described here is being performed. Prospects for a new UNCD MEMS technology will be discussed as well.